Symmetry and Middle Paleolithic Points: A Case Study of Iran's Middle Paleolithic Points

Nasim Feizi

Tarbiat Modares University

Hamed Vahdati Nasab (✉ hamedvahdati@yahoo.com)

Tarbiat Modares University

Research Article

Keywords: Middle Paleolithic, Projectile Point, Throwing, Symmetry, Drag

Posted Date: September 14th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-257471/v2>

License: This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Symmetry and Middle Paleolithic Points: A Case Study of Iran's Middle Paleolithic Points

Nasim Feizi* and Hamed Vahdati Nasab**

*Postdoctoral researcher, Department of Archaeology, Tarbiat Modares University, Tehran, Iran.

**Associate Professor, Department of Archaeology, Tarbiat Modares University, Tehran, Iran, Correspondent author

Abstract

The throwing capacity of Middle Paleolithic points has been an important issue since the discovery of the Neanderthal's toolbox. In the Middle Paleolithic, *Homo* (*Neanderthals* or *H. sapiens*) made thrusting points with limited or no throwing capability. Projectile points as a long-range weapon were replaced with the thrusting and guaranteed the survival of modern humans. Several attempts have been made to recognize the aerodynamic differences between Middle and Upper Paleolithic Points. However, up to now, far too little attention has been paid to the symmetry and projectile motion rules related to it. In this paper, symmetry and other morphological features, including

length, width, weight, cross-sectional area, flattening, and elongation, have been measured on 280 points collected from five Iranian Middle Paleolithic sites. In addition, the Iranian Middle Paleolithic data is compared with several Middle, Upper, and Neolithic sites outside of Iran. The results indicate that the evolution of symmetry alongside increased elongation, and proportionality in measurable characteristics was a critical factor in creating projectile points.

Keywords: Middle Paleolithic, Projectile Point, Throwing, Symmetry, Drag

1. Introduction

"Competition hypothesis" as an essential theory highlights the role of the aerodynamic ability of modern human's projectile points to overcome and finally extinct the Neanderthals (Shea, 2003). Shea did not have evidence to support the extensive use of stone-tipped projectiles in Africa, the Levant, or Europe until 40Ka (Shea, 2006). In the following researches, Churchill and Rhodes (2009) do subscribe to this view. They show evidence of diversity in Scapular and ulnar morphology within and between groups of Fossil humans and modern humans that attributes

the origin of the projectile point to modern man from Africa and at the same time as his presence in Europe is scattered in the land of Neanderthals (Churchill and Rhodes, 2009). However, Villa and Soriano could not accept this theory based on evidence from Ethiopia and Botswana. Nevertheless, Delpiane and his colleagues (2019) believed that late Neanderthals innovated projectile by backed artifacts that were hafted in different regions of Europe independently based on the large assemblage of data from unit A9 at Fumane Cave (Delpiane et al., 2019). On the other hand, Sano and his colleagues (2019)

provided contradictory evidence in southern Italy. According to microscopic analysis of backed lithic pieces from the Uluzzian site, they show that this projectile technology was conveyed to Europe from Africa at around 45 ka by modern humans (Sano et al., 2019). As it turns out, the issue is quite challenging. However, the general opinion is that Neanderthals could not make projectile points, although the later experimental and archeological evidence in Abri du Maras, France, and the Northern Iberian Peninsula rejects this view (Hardy et al., 2013; Rios-Garaizar, 2016). Therefore, one should look for a way to measure the throwing capacity of the lithic points specific to these two human groups separately. Accordingly, several experimental trials have been performed to investigate the throwing capacity of Middle Paleolithic projectile points (e.g., Shea et al. 2001; Shea et al., 2002; Sisk and Shea, 2009; Newman and Moore, 2013; Rios-Garaizar, 2016; Clarkson, 2016).

Most researchers generally focused on measuring the cross-section area and perimeter to determine the aerodynamic features of points and throwing power, especially in the Middle Paleolithic (Hughes, 1998; Shea, 2006; Shea and Sisk, 2011; Hardy et al., 2013; Wilkins et al., 2012 & 2014, Rios-Garaizar, 2016; Clarkson, 2016, Schoville et al., 2016; Mika, 2020; Sitton et al., 2020; Mullen et al., 2021). Although there has been much debate about the validity of the morphological impact of these factors on throwing capacity (For example, Clarkson (2016)), recent experimental researches seem to support their credibility (Schoville et al., 2016; Mika, 2020; Sitton et al., 2020; Mullen et al., 2021). So far, very little attention has been paid to the role of

symmetry in Paleolithic projectile's functions. Accordingly, this research aims to explore the relationship between symmetry and other morphological features in throwing capacity.

2. Archaeological background: The Iranian Middle Paleolithic sites

Iran with an area of 1.648.000 square kilometers is located in southwest Asia and surrounded by the Caspian Sea at north and the Persian Gulf and Oman Sea at south (Fig. 1). This area is rich in biological and geographical diversities; moreover, Iran is even more significant because of the presence of hominid remains in its neighboring regions (e.g., Shanidar in Iraqi Zagros, Dmanisi in northwest of Iran in Republic of Georgia and Teshik-Tash in Uzbekistan in north east of Iranian plateau). In addition to that, cultural remains of Paleolithic groups in the shape of lithic materials assigned to all Paleolithic subdivisions have been recorded in Iran in large numbers (Vahdati Nasab, 2010). During the last decade numerous Paleolithic field missions had led to the discovery of a handful of Paleolithic sites across the Iranian plateau among which are several Middle Paleolithic open sites that the points collected through systematic surface surveys of five of those are subject to this research (Fig. 1): Mirak, Chah-e Jam, The Mehran plain, Kuhrang, and Bandepey. These sites are located in very different landscapes across Iran. For instance, Mirak and Chah-e Jam are situated at the northern edge of the Iranian Central Desert in very dry and arid regions (Vahdati Nasab, et al., 2013; Vahdati Nasab and Hashemi, 2016). On the other hand,

Bandepey is a huge lithic scatter located at the southern coast of the Caspian Sea in a Mediterranean forest (Vahdati Nasab, et al., 2015). Mehran Plain and Kuhrang are both located at the Zagros Mountains; however,

Figure 1. The location of Middle Paleolithic sites on the Iranian Plateau

3. Methodological background: Projectile Physics Perspective

In 1998, Hughes examined the engineering of primitive weaponry (mass, cross-sectional area, perimeter, and the shape and durability variables from tips from Mummy Cave in detail. Accordingly, from an evolutionary point of view, it is divided into four groups, including the thrusting spear, throwing spear, spearthrower, and bow (Hughes, 1998).

In projectiles, what is interesting is that the experimental research revealed that there is a direct relationship between the existence of the tip and its penetrating power (Wilkins et al, 2014 & 2012). In addition, there is an inverse relationship between the size of triangular stone arrow tips and the amount of penetration (Mika et al., 2020). For example, we can see such a relationship in the projectile point of the Uluzzian site (around 45 ka) in southern Italy (Sano et al., 2019), the arrow and arrowheads of Eastern North America in the late first millennium AD (Mika et al., 2020), and the Neo-Assyrian bronze arrowhead in the site of Ziyaret Tepe, located in southeastern Turkey (Mullen et al., 2021).

However, John Shea emphasizes that in the Levant, Africa, and Europe, the cross-section of the Middle Paleolithic points is large. Thus, these points are not useful tools for penetrating into a target's body. Therefore, the lithic points were not able to throw until some 40000 years ago (Shea,

205 2006). On the other hand, Clarkson using
 206 the ethnographic and experimental data has
 207 proven that the cross-section area (TCSA)
 208 or perimeter (TCSP) is not a determining
 209 factor in the depth of penetration (Clarkson,
 210 2016). Nevertheless, experimental and
 211 archeological results in the northern Iberian
 212 Peninsula's Middle Paleolithic point
 213 assemblages support the role of these
 214 factors in throwing a projectile (Rios-
 215 Garaizar, 2016).

216 Therefore, it is important to consider the
 217 situation from the point of view of physics.

218 Based on the penetration equation,
 219 Prehistoric Projectile penetration is affected
 220 by four variables: mass (M), velocity (V_0),
 221 tip cross-sectional area (A), and projectile
 222 shape (C), and drag force predict the most
 223 optimal shape for penetration (Hughes,
 224 1998).

$$225 \quad \text{Penetration} = \frac{MV_0}{CA} \quad (2)$$

226

227 (Sperrazza and Kokinakis, 1968, p. 163)

228

229 The following formula (3) also determines
 230 the drag force or the friction force.

231

232

$$233 \quad D = \frac{1}{2} \rho V_t^2 A \cdot C \quad (3)$$

234

235

236 These formulas show a direct relationship
 237 between the increasing coefficient of the
 238 drag and reducing speed, between the drag
 239 and cross-section areas. The drag force
 240 formula shows that the smaller the cross-
 241 sectional area, the lower the drag force
 242 acting upon the projectile. Accordingly,

243 from the drag reduction point of view, the
 244 cross-section area can be a useful factor.
 245 Furthermore, in the throwing motion, the
 246 shape of the trajectory and its range is
 247 affected by the drag (Ang, 2013).
 248 Accordingly, it seems that the cross-section
 249 area affected the drag amount although its
 250 effect depends on other factors. For
 251 example, the joint between the point and the
 252 shaft is a key criterion in the performance
 253 of the spear (Pétillon et al., 2011).

254 On another hand, given the Mechanics of
 255 fluids, it is evident that what is essential for
 256 effective throwing is a projectile's shape
 257 and fluid pressure force that acts upon its
 258 form. Interestingly, Theodore von Kármán
 259 focused upon the impact of these
 260 components in organisms moving, such as
 261 Trout swimming. He compared the dorsal
 262 and ventral parts of the trout body with a
 263 modern airfoil; therefore, his research was
 264 one of the first studies to draw attention to
 265 trout fish swimming behavior and
 266 overcome the drag. He stresses that there is
 267 a relationship between body shape and
 268 reducing drag in organism life (Von
 269 Kármán, 1963: 7-8). This result raises a
 270 pertinent question. What kind of body
 271 shape causes to decline sharply in the drag?
 272 To put it another way, what impact does the
 273 projectile shape have on its aerodynamic?

274 For Vogel, the characters that we can see in
 275 the body forms of the tuna, mackerel, or the
 276 design of modern airfoils, including slender
 277 shapes, blunt noses, and sharp trailing are
 278 what caused to minimize the drag. (Vogel,
 279 1994: 147-8). We know that the fish body
 280 with such characters has a symmetrical
 281 shape. Generally, the fluid pressure that
 282 acts on the projectile depends on its shape.
 283 This vital principle was obtained based on
 284 studies from the macroscopic to the
 285 microscopic scale. For example, fish

286 swimming at the macroscopic level and
287 fungal spores at the macroscopic level are
288 examples that are well-studied (Vogel,
289 2005). In addition to biological samples, the
290 navigation industry emphasizes physical
291 features (Roper, 2008). It is worth
292 mentioning that drag minimization is the
293 only way to an accurate and useful throw.
294 However, how can we minimize the drag
295 force on something moving through the air?
296 Applied science research answered this
297 question using the laws of physics.

298 The fact that the drag forces are directly
299 proportional with the coefficient of
300 viscosity (Wilson, 2000: 322). Viscosity is
301 a parameter that indicates the degree of
302 resistance to the flow of the fluid, and liquid
303 viscosity is more than gas viscosity. This
304 parameter is a determining factor in the
305 flow pattern (Adams et al., 1960: 332). So
306 that, viscosity is inversely related to inertia,
307 and the relative of these two parameters is
308 called the Reynolds number. It is necessary
309 to mention that when the viscosity is zero,
310 the fluid will continue to flow indefinitely
311 because the resistance to flow is zero. Of
312 course, such an absolute zero does not
313 happen in the real world. In contrast,
314 viscous effects are dominant in low
315 Reynolds number flows; therefore, the flow
316 is slow and layered (Oteh, 2008: 311).
317 Interestingly, the minimal drag shape has
318 been defended for slowly creeping flows in
319 Reynolds (Re) equals zero (Pironneau,
320 1973 & Bourot, 1974). Accordingly, Roper
321 and his colleagues have proven that the
322 shape of the body that minimizes the drag
323 force is highly symmetrical at moderate
324 Reynolds. They show that although the
325 perfect projectile is weakly asymmetric, the
326 projectiles preserve quite fore-aft
327 symmetry. However, the flow around such
328 bodies becomes markedly asymmetric
329 (Roper et al., 2008). On the other hand,
330 during an experimentally conducted
331 research, it is shown that rounded and sharp

332 noses in a symmetrical projectile have a
333 better performance than flat noses and
334 spherical ones. Nevertheless, the round
335 nose projectile has the best performance in
336 long distances, while the sharp nose has a
337 close performance with a round nose, it is
338 more suitable for hunting due to its greater
339 penetration (Salimipour et al., 2018). Thus,
340 it should be noted that the shape and size of
341 a projectile are effective in determining
342 drag (Ang, 2013). Accordingly, it seems
343 possible that in different fluids, both in
344 ultrasound and in ultrasound, the degree of
345 symmetry has a significant effect on
346 successful throwing. Perhaps it can explain
347 why most of the Upper Paleolithic points
348 are throwing-capable. Moreover, an
349 accurate projectile may be considered as a
350 consequence of changing morphological
351 features with the evolution of the
352 symmetry.

353 **Materials and Methods**

354

355 There are different ways to measure
356 symmetry in two-dimensional space.
357 However, 3D methods have recently
358 demonstrated that the third dimension and
359 the degree proportion of preparation
360 removals are critical for increasing
361 symmetry (Feizi et al., 2018). For example,
362 based on previous researches on the points
363 of the mentioned site, it was proved that the
364 deviation of symmetry in most Middle
365 Paleolithic points has a similar pattern
366 (Feizi et al., 2019). We think that the results
367 are likely to be related to the interaction
368 between the proportion of preparation
369 removals and symmetry and the effect of
370 these interactions on morphology (Feizi et
371 al., 2018; Feizi et al., 2019). Thus, we
372 calculated the deviation from the symmetry
373 of 5 Iranian areas with the three-
374 dimensional method. But for comparing our

375 data with other sites, we used a
376 straightforward method called the
377 quadrangle technique.

378 In summary, in our 3D method, we prepare
379 two three-dimensional models from each
380 point. One of them is a computable surface
381 to measure the symmetry of a point. This
382 surface is called the Mesh (or Test) model.
383 We will have meshed all surface points
384 using Geomagic software ¹(version 2013). By
385 this, the software will have passed a triangle
386 from any three points that are not on a
387 straight line. This operation leads to doing
388 math calculations on a triangulated surface.
389 For example, if we want to calculate a point
390 area, the software quickly collects the
391 triangle areas that covered all Surface
392 points and calculates the total area of that
393 point. In addition to the countable surface,
394 we make a Reference Model (CAD) to
395 calculate the deviation of each point from
396 the symmetry mode. The CAD is an
397 incomputable surface in which all
398 topographic characteristics are determined
399 precisely and only used for comparison.
400 Then the two levels are aligned. So that, the
401 left side of the point set on the right side,
402 just like a veneer. With this logic, the more
403 symmetrical the two sides of the point are,
404 the more accurately the surfaces are placed
405 on top of each other. In this position, the
406 upper surface acts as a suitable veneer. This
407 alignment is done with a particular
408 technique and the most accurate software.
409 The software is comparing the symmetry of
410 the point concerning all the topographical
411 features of the two sides. At the final step,
412 the degree of deviation from symmetry is
413 defined as a series of numbers, and then the
414 obtained data are analyzed by SPSS 23
415 (Feizi et al., 2018).

416 In the paper, any lithic point or any other
417 2D or 3D dimensional shape is inscribed in
418 a quadrangle so that four (or three) vertices
419 of the lithic point are tangent to the four
420 sides of the quadrangle. Next, MB-ruler² is
421 used to cut the quadrilateral from its center.
422 It is worth noting that this ruler was
423 designed by Markus Bader. The ruler is a
424 high-flexibility ruler that measures
425 distances and angles from a computer
426 screen as well as distances from maps and
427 aerial photographs. Thus, without paying
428 attention to the point, the quadrangle is
429 halved. It means that if a point is
430 symmetrical, it will be half from its
431 symmetrical axis with the quadrangle.
432 Accordingly, as shown in Figure 2, the
433 quadrangle is halved, and each triangular
434 lithic point is divided into two smaller
435 triangles (the right and left), and the areas
436 of the two triangles are calculated (Fig. 2).
437 If the left and right are equal, then the
438 difference between the two sides of the
439 lithic point will be equal to zero. Hence, the
440 symmetry is perfect. However, perfect
441 symmetry is impossible in reality, and there
442 is always a numeric value ($S_L - S_R \neq 0$).
443 This numeric value is the deviation of ideal
444 symmetry (D.S.) (3), and I.D.S. (4) is equal
445 to D.S divided by the total area of a lithic
446 point (S.T.) (Feizi et al., 2018).

$$D.S = |S_L - S_R| \quad (3)$$

$$I.D.S = \frac{|S_L - S_R|}{S_T} \quad (4)$$

449 Accordingly, we compared the deviation
450 of symmetry of lithic points in the Middle
451 and Upper Paleolithic using the quadrangle
452 technique.

453 It should be noted that due to the lack of
454 access to the 3D image of other areas, we

¹ Geomagic®, Morrisville, North Carolina

² © Markus Bader - MB-Software solutions

used the 2D method for comparison. The advantage of the two-dimensional method is the simplicity of this method so that even without the use of calculation I.D.S. only by enclosing the point in a quadratic and passing the axis through its center can the differences be intuitively compared.

In this research, the 280 Iranian lithic points were scanned in the Rock Mechanics

Laboratory, Tarbiat Modares University (Tehran, Iran), using Optic Scan3D Scanner, and Version 2.2. Once the digitization was completed, 3D images were analyzed and compared by Geomagic software (version 2013). Also, a Marcus Bader Ruler was used to bisect each lithic point (version 5.1). Then, their symmetry was measured in two- and three-dimensional space.

Figure 2. The quadrangle is halved, and each triangular lithic point is divided into two parts (Feizi et al., 2018).

We measured the deviation of symmetry lithic points in the middle Paleolithic sites of Iran, Including Mirak, Chah e jam, Mehran Plain, kouhrangh, and bandepay by 3D method (Table 3, 4).

In total, 280 points were selected from Iranian sites for this research, which all have been confirmed for having diagnostics signs of Middle Paleolithic industries (e.g.,

Levallois technique, prepared and faceted platforms, retouches, etc). Table 1 summarizes the quantity of Iranian Middle Paleolithic points that were chosen for this research. In addition, we studied the Upper Paleolithic points in Iran, including Yafteh cave (Otte, et al., 2007), Arjaneh (Hole, 1970), Boof cave (Ghasidian, 2012), and Galeh ghosheh site (Conard, et al., 2009).

Site	Mirak	Chah-e Jam	Bandepey	Kuhrang	Mehran Plain
Number	143	57	27	22	31
Total	280				

Table 1. Iranian Middle Paleolithic points

In the second stage, considering the effect of other morphological features such as weight, length, width, and elongation on the amount of penetration and drag, we compared these features in 5 Iranian areas with several areas inside and outside Iran. These comparisons, which were performed to observing possible evolutionary changes, included comparing the points of the Middle Paleolithic period with each other as well as the points of the Middle and Upper Paleolithic periods. Thus, the morphological features related to the point's aerodynamics were measured in the Iranian sites and compared with other Paleolithic sites outside Iran. These sites include Tor Faraj (70-50k Ka) in Southern Jordan (Groucutt, 2014), Kathu pan1 (291 45) in southern Africa (Wilkins and Chazan, 2012), Kebara (60-50 Ka), Hayonim (100-90 Ka), and Qafzehin (100-90 Ka) Levant (Shea, 1988), and also Sibudu, Rose Cottage in the Middle Stone Age in Africa and Bouheben in the Middle Paleolithic of

552

553

the southwestern French (Lenoir, 2006), some dart and arrowhead of the collections of the American Museum of Natural History (AMNH) (Thomas, 1978), and finally, the points of the Neolithic sites of Levant (Gopher, 1994). Table 2 summarizes the number of points mentioned above that were chosen for comparative analysis. These sites were not selected at random because the main aim of the selections is to cover an extensive period. On the other hand, we selected sites where the researchers measured the morphological features of the lithic points, and so it was possible to compare the features. We compared different dimensions of our points with experimental points made by Rios-Garaizar (2016). Rios-Garaizar's points are 24 Middle Paleolithic points made using the Levallois technique with flint from Morocco. These points fitted the expected variability of Middle Paleolithic points (Rios-Garaizar, 2016).

The Middle Paleolithic sites (Groucutt, 2014; Lenoir, 2006; Thomas, 1978; Shea, 1988)								
Site	Tor Faraj		Sibudu	Rose Cottage		Bouheben		AMNH
Number	107		125	43		95		128
Site	Rosh Ein Mor			Tabun	Skhul B		Kebara	
Number	102			80	27		239	
Total								946
The Levantine Neolithic site (Gopher, 1994)								
Site	El-Khiam	Helwan	Jericho	Byblos	Amuq	Ha-Parsa	Nizzanim	Herzilya
Number	274	1265	1398	1934	1160	371	341	43
Total								6786

554

Table 2. Non-Iranian Paleolithic and Neolithic points.

555

It is worth mentioning that, in this research; except for symmetry, measurement

methods are applied that had been used previously to measure the lithic points of

sites out of Iran (Groucutt, 2014; Hardy et al., 2013; Rios-Garaizar, 2016; Sisk and Shea, 2011). In addition, the one-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the means of TCSA and or other morphological features such as weight, length, and TCSP to compare the throwing power of the points.

3. Results

We measured the deviation of symmetry of lithic points in the middle Paleolithic sites of Iran, Including Mirak, Chah e jam, Mehran Plain, kouhrangh, and bandepay by 3D technique (Table 3, 4). Table 4 presents the summary statistics for all sites. Considering all the evidence (Tables 3), it seems that all five sites have a large number of symmetrical points and a small number of asymmetrical ones compared to the total number of points that were studied on each site. Figure 3 shows the mean of deviations in these sites. The result is then compared with six sites outside Iran in the 2D method, enclosing at a quadrat without calculating the I.D.S. The reason for using the 2D method for other sites is the lack of access to 3D images of them.

site	Variable	n	dmax1	dmax2	dvag1	dvag2	RMS
Mirak	Mean	133	2.88	-2.81	0.70	-0.69	0.89
	Std. deviation	133	0.28	0.39	0.24	0.29	0.38
Chah-e jam	Mean	48	2.77	-2.72	0.67	-0.64	0.89
	Std. deviation	48	0.38	0.42	0.27	0.25	0.38
BandePey	Mean	23	2.6	-2.7	0.9	-0.8	1.10
	Std. deviation	23	0.6	-0.6	0.4	-0.6	0.4
Mehran Plains.	Mean	30	2.3	-2.34	0.70	-0.67	0.92
	Std. deviation	30	0.46	0.47	0.25	0.26	0.27
Kuhrang	Mean	21	2.7	-3	0.87	-0.86	1.1
	Std. deviation	21	1.3	0.52	0.26	0.3	0.27

Table 3. Summary of deviation analysis of our Iranian site. Dmax (+), the largest positive difference between two surfaces; dmax (-), the largest negative difference between two surfaces; dvag (+), mean the positive difference between two surfaces; dvag (-), means the negative difference between two surfaces; RMS, root mean square of deviation.

site	Number	Mean	Standard deviation	Proportion of unsymmetric/symmetric points
Mirak	133	0.89	0.3	0.15
Chah-e jam	48	0.87	0.25	0.2
BandePey	23	1.09	0.3	0.2
Mehran Plains.	30	0.86	0.3	0.2
Kuhrang	21	1.1	0.45	0.09
Total	225			

site	Number	Mean	Standard deviation	Proportion of unsymmetric/symmetric points
Mirak	133	0.89	0.3	0.15
Chah-e jam	48	0.87	0.25	0.2
BandePey	23	1.09	0.3	0.2
Mehran Plains.	30	0.86	0.3	0.2
Kuhrang	21	1.1	0.45	0.09
Total	225			

Table 4. Descriptive statistics of the symmetry of lithic points in five sites in Iran.

Figure3. Boxplots comparing the mean of deviations in all sites.

In the second stage, as can be seen from Appendix Table 1, 2, and Figure 4 the means of morphological features in Tor Faraj is comparable with the Iranian sites; these tables present the summary statistics to compare the lithic points of Middle Paleolithic sites of Iran and Tor Faraj. In regard to size, sites such as Khuhrang and Bandepay usually have larger lithic points than Tor Faraj and other Iranian sites including Cha-e Jam, Mirak, and the Mehran Plain. Nevertheless, the elongation

of all Iranian points is smaller or equal to Tor Faraj's points. In other words, despite the large weight, area, volume, TCSA..., they have little elongation. Although, the Sibudu, Rose Cottage, and Bouheben's points are less elongated, despite being comparable in height to Iranian and Tor Faraj's points.

According to these morphological features, we believe that Iranian points, the same as Tor Faraj's points, do not have the

capacity of throwing. The experimental use of hand-made points similar to Mirak's points proved this claim (Mehrpoor Moghadam, 2009). In the thesis, a point was constructed with the average morphological features of Mirk points. This point was attached to three hafts with different weights of 500 g, 800 g, and 1200 g and was thrown to a Lamb meat several times. The launches were done from different distances of 10 meters and fewer. Despite the contact with the meat, these spears did not penetrate, and only a scratch effect was seen (Mehrpoor Moghadam, 2009).

Based on the above results, one reason for this could be the lack of the ability to create perfect symmetry in the points, and insufficient elongation due to the proximity of length and width values is a main factor in increasing the drag and decreasing

penetration depth. On the other hand, approximately equal in width to the length of the arrowhead is the main factor in their durability (Van Buren, 1974). However, based on the Mummy Cave tip, Hughes shows that there is a trade-off between increasing penetration depth or durability (Hughes, 1998). So, he believes most projectiles will be designed to increase penetration, so unlike the thrusting spears, they are less durable (Hughes, 1998). The South African Middle Stone Age points in Sibudu, Rose Cottage and the Middle Paleolithic points in the South West of France supported this claim (See Table 5). Nevertheless, the points that were made by Rios-Garaizar demonstrated that at least some Mousterian points could be used as throwing spear tips (Rios-Garaizar, 2016). It is worth bearing in mind that Rios-Garaizar used eight of his experimental points to perform throwing motions.

668

Site	Length (mm)	Width (mm)	Thickness (mm)	Weight (gm)	TCSA (mm ²)	Elongation	Flattening
Bouheben	57.4	32.1	10.7	18.9	177	1.8	3
Sibudu, final MSA	46.9	27.7	7.3	10.7	116.2	1.7	3.8
Sibudu, RSp-MOD	41.8	27	8.1	11.9	117.7	1.6	3.3
Sibudu, layers below RSS	45.3	28.7	9.6	14.2	139.4	1.5	3
Rose Cottage	36.6	21.4	7.1	5.2	74	1.7	3

669

Table 5. The morphological measurements for spear points from Sibudu, Rose Cottage and Bouheben in the Middle Stone Age and the Middle Paleolithic (Villa and Lenoir, 2006).

672

673

674 .

Figure 4. Comparison of morphological features of Mirak, Chah e jam, Mehran Plain, kouhrangh, bandepay, and tour Faraj points

Therefore, we need to know whether or not any differences of importance existed between the mean TCSA in our middle Paleolithic points with Rios-Garaizar's projectiles. We tested this possibility with an ANOVA (one-way). The reason for this is the comparison of the throwing power of our Iranian Paleolithic points with his experimental points. Because we know that the TCSA has a great effect on the throwing power, and Rios-Garaizar has concluded by testing its points that they do have this ability due to the large cross-section. So if the average cross-sectional area of our points is equal or significantly smaller than his projectiles, our points have probably thrown capacity. The calculated value of F

was 14.93, and the significance level ($S = 0.000$). The null hypothesis (no significant difference) is therefore rejected, suggesting that the difference between the TCSA means is significant. Results of the ANOVA further indicated a need to compare the mean of TCSA for all sites. The least significant difference (LSD) test helps to identify the TCSA whose means are statistically different. Results of the LSD tests indicate that Rios-Garaizar's projectiles have a statistically significant difference with the points from Mehran Plain, Bandepay, and Kuhrang site. In other words, as can be seen from the Boxplots below (Figure 5), the points of these three areas have a larger TCSA. While the rest of

the points – Mirak and Chah-e-jam’s points – are similar to Rios-Garaizar’s experimental examples (Fig. 4). It seems possible that the reason for the large TCSA in the two sets of Bandepey and Kuhrang site is on-site availability and abundance of the raw material (Roustaei, 2010; Vahdati Nasab et al., 2017), which has caused tool makers to pay less attention to shaping their tools and deviate too much from symmetry (Feizi et al., 2019). In addition to Point morphological features, the physical characteristics of shafts, such as their length can be decisive (Rios-Garaizar, 2016), so that the shaft has a direct effect on the penetration depth (Salem and Churchill, 2013). Interestingly, the Rios-Garaizar experimental shafts, are taller (220, 200, 180 lengths). In addition, Solutrean shoulder points are other examples that look asymmetrical but act well due to the use of the shaft (Chadelle et al., 1986). In these cases, it seems that joining the shaft and point in the best possible way is the main reason for the suitable functioning. In these cases, According to the quadrangle

technique, it can be said that the axis of the more symmetrical part with the axis of the shaft adjusts, and the more asymmetrical enters the shaft (Figure 6).

The left and right points are adjusted around the shaft axis so that the tool is approximately the same shape, size, weight, and height on both sides, and as the axis elongate, the destructive power of the weapon increases (Feizi et al., 2018).

Thus, the smaller the deviation from the symmetry and the more its axis of symmetry coincides with the shaft axis, the more symmetrical it is, the greater the accuracy of the throw (Salem and Churchill, 2013).

In general, we do not have information about our shaft lengths. Based on this, we ignored the shaft and only research the ability to throw our points. Given the morphological features mentioned, we can say that the Middle Paleolithic points cannot be thrown.

Figure 5. Comparison of TCSA of Mirak, Chah e jam, Mehran Plain, kouhrangh, bandepey, and Experimental points

Figure 6. The axis of symmetry of the Solutrean shouldered points approximate the main axis of the shaft.

In the Upper Paleolithic, for the first time, Homo sapiens made the dart (Shea, 2010), and the arrowhead as a weapon was associated with the darts (Shea, 2006), although, later replaced it (Hughes, 1998). Some scientists believe that the ability to make throwing weapons eventually enabled Homo sapiens to leave out of Africa and enter temperate western Eurasia (Shea, 2013). Shea is among archaeologists who believe that cross-sectional area is a vital factor in the ballistic power of the weapon (Shea, 2006). Statistically, Shea shows that the TCSA values of the points are significantly different between the two types of stone projectile points (spear-thrower dart tips and arrowheads) and spear points. He obtained this result by comparing the TCSA values of stone projectile points to hypothetical Middle and Upper Paleolithic stone projectile points from Africa, the Levant, and Europe. Aerodynamically, at the moment, it is

evident that a perfect projectile has an optimal shape. However, the question stands: what morphological changes caused such a success in the Upper Paleolithic points?

In 1976, Thomas compared the 128 numbers of darts (10 number) and arrowheads (118 number). In line with Shea's aim, we need to know whether or not any differences of importance existed between the mean TCSA in our middle Paleolithic points with Thomas's projectiles. We tested this possibility with an ANOVA (one-way). The calculated value of F was 41.46, and the significance level ($S = 0.000$). The null hypothesis is therefore rejected, suggesting that the difference between the TCSA means is significant. Results of the ANOVA further indicated a need to compare the mean of TCSA for all sites. The least significant difference (LSD) test helps to identify the

813 TCSA whose mean are statistically
 814 different. Results of the LSD tests indicate
 815 that Thomas's projectiles have a statistically
 816 significant difference from our Iranian
 817 points, although darts and arrowheads do
 818 not differ from each other significantly
 819 (Fig. 7). Thus, our Iranian middle points
 820 have larger TCSA than Thomas's darts and
 821 arrowheads.

822 In addition, we calculated the means of
 823 other morphological features measured by
 824 Thomas. As can be seen in Table 6, the
 825 darts have been taller, thicker, and have
 826 wider tips than the arrowheads, whereas all
 827 of them are much lighter than the Middle

828 Paleolithic points. However, elongation and
 829 flattening are approximately equal
 830 (Appendix Table 1, 2, and 7). In addition,
 831 arrowheads have shorter and smaller (in
 832 diameter) fore shafts than the darts.

833 As can be seen in Table 8, in the Neolithic
 834 Levant sites, the projectile points have the
 835 same average length as the Middle and
 836 Upper Paleolithic points. In contrast, they
 837 have less width and thickness. It should be
 838 noted that we calculated the means of
 839 morphological features of the Levantine
 840 points that were published by Gopher
 841 (1994).

842

843

844

845 **Figure7.** Comparison of TCSA of Mirak, Chah e jam, Mehran Plain, kouhrangh, bandepay, and Thomas's Dart
 846 and arrowhead

847

848

849

Tools	n	Length (mm)	Width (mm)	Thickness (mm)	Neck Width(mm)	Weight (gm)	TCSA (mm2)	Foreshafte (mm)
Dart	10	46.2	22.9	4.9	13.7	4.38	56	105
Arrowhead	132	31.1	14.7	4	10	2.07	33	71

Table 6. The morphological measurements for arrowheads and dart tips Tomas's sets

Tools	n	Elongation	Flattening
Dart	10	2.02	4.7
Arrowhead	132	2.12	3.7

Table 7. The measurements of elongation and flattening for arrowheads and dart tips.

sample	Length (mm)	Width (mm)	Thickness (mm)	TCSA (mm2)	Elongation	Flattening
Helwan points	32.41	9.4	3.1	20	2.5	4.2
Jericho points	52.04	14.4	4.3	31	3.6	3.3
Byblos points	49.83	13	4.1	27	3.8	3.2
Amuq points	52.85	12.3	4	26	4.3	3.1
Ha-Parsa points	28.8	11.2	3.3	18	2.6	3.4
Nizzanim points	31.83	10.9	3.6	20	2.9	3.03
Herzilya points	28.24	12.2	3.7	23	2.3	3.3

Table 8. The morphological measurements for the arrowheads of the Neolithic Levant (Gopher, 1994).

Discussion and Conclusion

The third dimension of the lithic points is a critical factor in creating symmetry. It is necessary but not sufficient to have a two-dimensional symmetry (length and width), although the third dimension seems determinative. It means that in addition to symmetrical appearance, realistic symmetry is also necessary for the useful function of a lithic point (Feizi et al., 2019).

Thus, both sides of the lithic point must be in similar conditions regarding the removal depth. Although despite the existence of a symmetrical appearance, some lithic points do not have realistic symmetry. Several unsymmetrical points have been recorded in the Iranian sites (Fig. 8). It was shown that the more conscious attention is, the more regular the pattern preparation is. Accordingly, the lithic point is more symmetric (Feizi et al., 2018) (Fig. 9).

Figure 8. The unsymmetrical points.
(The dorsal side of the CAD (gold color)
and mesh (red color) models overlap)
(Feizi et al., 2018).

Figure 9. The symmetrical point with a
regular pattern in terms of ridges and troughs
(Areas of the same color have the same depth and)
prominence (Feizi et al., 2018).

Overall, the evidence from our previous study revealed that there is a significant relationship between sites and the degree of deviation from symmetry (Please see Feizi et al., 2019). The sites can be divided into two groups in regard to this degree of deviation. Points in group 1, which includes Mirak, Chah-e jam, and Mehran Plain, are more symmetrical than those of group 2 (Kuhrang, BandePey). In addition, retouch had a key role in achieving and modifying

symmetry. In all sites, retouch was used for achieving symmetry of the edges and shaping the lithic points, particularly in group 1 (Table 9). To sum up, a common pattern of deviation from symmetry is apparent in each group, and this suggests a difference between groups in the amount of conscious attention which can be the result of access to raw materials (Feizi et al., 2019).

site	N	Means	Std
Mirak	148	4.02	0.14
Chah-e jam	58	5.18	0.18
BandePey	27	3.4	0
Mehran Plains.	31	4.66	0.19
Kuhrang	23	3.09	0.26

Table 9. The percent of retouch of the lithic points in all sites by Clarkson Measurement Method (2002) (Faizi et al., 2019).

The quadrangle technique could reveal a similar pattern for deviation of symmetry in the Middle Paleolithic points. It seems likely that Neanderthals did not attempt to create specific symmetrical tools. To put it another way, they have been convinced of general symmetry (Feizi et al., 2019). When these lithic points are located in the quadrangle that measures the deviation of symmetry, the axis is passing the left or

right shoulder. Therefore, the highest axis of symmetry is parallel or makes an angle. In a similar vein, whenever the axis of symmetry is crossing over the midline, the two sides of points do not have similar morphology (Fig. 10 -1, 10 -2, 10 -3). They also used points with larger TCSA to make projectile points only for close hunting (Shea, 2006).

Figure 10-1. In the middle Paleolithic, hominids had not carefully performed symmetry (Feizi, 2018).

Figure 10-2. The deviation from symmetry in the Northern Iberian Peninsula MiddlePaleolithic Mousterian Point (Rios-Garaizar, 2016).

Figure10-3. Examples of Middle Paleolithic points from northeast Africa and southwest Asia. 1, 2: Jebel Katefeh, 3. Aybut al Auwal, Oman. 4, 5: Nazlet Khater, Egypt (Groucutt, 2013).

In general, the situation looks completely different in the Upper Paleolithic. The study of projectile points of the sites mentioned above in Iran (Yafteh cave, Arjaneh, Boof

cave, Galeh ghosheh site) shows that a serious change has been made in the administration of symmetry in the Upper Paleolithic points (For example, Fig. 11).

Figure 11. Several symmetrical projectile points (Arjaneh point) in 1. Qaleh Gosheh 1 (Conard, et al., 2009), and 2. Yafteh cave (Hole, 1970).

In addition, the comparison of the Iranian Middle Paleolithic projectile points with those from outside Iran such as Levantine points (Emireh, Umm el Telel, Ksar Akil, El Wad points), (Shea, 2013: 141), the West European points (Chatelperronian, Gravette, Font Robert, Solutrean), Middle Stone Age of Africa (symmetrical triangular flakes, foliate bifaces, unifacial points, tanged points) demonstrate similar patterns.

Using the quadrangle technique for the Upper Paleolithic points indicates that symmetry has evolved a high percentage compared to the Middle Paleolithic period. Interestingly, it seems that *Homo sapiens* paid special attention to the practical aspects of symmetry. Accordingly, they

made the symmetrical points that the axis of symmetry generally crosses over the midline of, and its two sides have the same morphological figures and thickness (Fig. 12). Although there are many unsymmetrical points at this time, it seems that increasing the cognitive capacity of symmetry implementation causes to make a perfect projectile since the Middle Paleolithic period. In the Upper Paleolithic period, all points are not projectile or spear points; they might be knives or have other functions (Newman and Moore, 2013). Therefore, not all of the Upper Paleolithic points need to have optimal symmetry. However, as outlined earlier, perfect symmetry is impossible in reality, and there is always a numeric value as the deviation of symmetry.

Figure 12. The samples of the upper Paleolithic points in Europe: (1) small Solutrean unifacial point (Roc de Sers, France), (2) Solutrean bifacial point (Founeau du Diable, France), (3) large Solutrean unifacial point (Laugerie-Haute Ouest, France), and southern Africa: (4,5) Still Bay points (Skildergat, South Africa), (6) bifacial point (Porc Epic Cave, Ethiopia), (Shea, 2006).

In the Upper Paleolithic period, it seems that balance and realistic symmetry are created. The reason for this is that *Homo sapiens* started to pay attention to the thickness of lithic points. Tool efficiency may explain why *Homo sapiens* focused their attention on making symmetrical points. Unfortunately, we did not have enough Projectile points to measure 3D symmetry for the Upper Paleolithic points. However, the indirect documents such as the decreasing thickness, weight, width, and increasing degree of their preparation cause the possibility of optimal symmetry.

Accordingly, we believe that symmetry was evolving in the Paleolithic period, and the deviation of symmetry affects the performance of throwing. In this research, in addition to symmetry, other morphological features such as elongation, area, weight, and cross-section were measured. In the later period, it seems that this problem can be solved. Our reason is that for making a perfect projectile to reduce aerodynamic drag, we need a cylinder body, a blunt nose, and two sharp trailing edges (Roper, 2008) like a fish, Dartfish, or maybe a dart. Another critical factor for the symmetrical projectile is that if the maximum cross-section area is approximately in the middle length, the drag will be the least (Sears, 1974).

The evidence shows that generally, arrowheads and darts are perfect projectiles (Thomas, 1978); as we can be seen in Table 7, the mean of darts and arrowheads elongation respectively are 2/02 and 2/21 with the cross-sections that respectively are 56 and 33. A simple mathematical proportion proves that if Mirak's points with this mean ($=51/9$) are projectiles, the means of the elongation will be $3/53$ approximately. At the same time, this is equivalent to 1.99 for Mirak's points. On the other hand, as can be seen in Appendix Tables 1, 2, in the Middle Paleolithic, generally cross-section area is not located at the middle length of points; as a result, the drag could not be minimum. Thus, the shape of the trajectory is not standard, and throwing is not distance hunting or executed correctly.

What is interesting in this data is that in Jericho and Amuq projectile points (Table 8), The Neolithic sites of the Levant, which are about the same length as the Mirak's point, are more elongated and much thinner. Data from Appendix Tables 1, 2, and Table 5 can be compared with the data in Table 8. While the result in most Middle Paleolithic sites (including Mirak, Chah-e-jam, Khuhrangh, Bandepey, and Mehran in Iran, and Torfaraj in Jordan and Bouheben in the southwestern of French, and middle Stone Age of Sibudu and Rose Cottage in Africa) is quite contrary. In these Middle Paleolithic sites, we do not have the points with geometric proportions and enough elongation to overcome the drag. Based on a t-test, Thomas showed that arrow fore shafts are undeniably smaller (in diameter) than dart fore shafts (Thomas, 1978). However, morphologically, the darts are larger than the arrowheads and have longer fore shaft than arrowheads. This relationship may be due to the created proportion and the throwing power of the points; the subject needs further investigation.

on the other hand, based on experimental data, some researchers focused on fracture mechanics to identify projectile use and penetrating characteristics (please see Fisher et al., 1984; Odell and Cowan, 1986; Dockall, 1997; Plisson, 2005; Iovita et al., 2013; Rots and Plisson, 2014; Coppe and Rots, 2017). By Dockall, There are unique fracture patterns of the projectile (Dockall, 1997), which can be the result of attachment to the handle or the impact of physical contact (a Kufel-Diakowska, 2016). However, researchers warn that large archaeological samples and examination of all types of wear a projectile in these samples are needed to identify the projectile's performance from fractures

(Rots and Plisson, 2014). Accordingly, using an attribute-based approach, Coppe and Roth (2017) show that there is a clear difference between the bow and the spear-thrower in terms of the fracture surface as a result of the type of contact. So that the distal location of an arrow is damaged by contact with bone, while due to contact with skin, the mesial location of a dart point is fractured (Coppe and Rots, 2017).

In ballistic, the fact that the target is also a criterion and will significantly affect the results (Rots and Plisson, 2014). Thus, a hard target needs a perfect projectile. So that, an oblique contact leads to the formation of the mesial scars, whereas, an oblique contact itself is a consequence of a deviation of the projectile (spin calibration) (Coppe and Rots, 2017). The deformation and fracture of the target as a contact problem between the target and the projectile is essential (Rodriguez-Millan et al., 2018). In addition, one of the most important aspects of the geometric design of a projectile is predicting the penetration depth (Wingrove, 1973). It seems that the penetration depth of an arrow is more than the dart (Hughes, 1987). In addition, experimentally, the spin of an arrow is much more stable than a dart, while an arrow is less likely to hit the target under this angle that will cause a dart to hit the skin under an oblique angle (Coppe and Rots, 2017). It should be noted that the cross-sectional area, the shape, and the mass-velocity relationship of a stone tip affected its penetration depth (Hughes, 1987). However, in experimental throws on an animal carcass, researchers show that in terms of penetration, retouched and shaped points had almost the same performance as unretouched and unformed points (Odell and Cowan, 1986 and Churchill, 1993), although, these results are intragroup and

1141 relate to only certain types of points with 1173
 1142 almost identical morphology. For 1174
 1143 Andrefsky, the production of formal tools 1175
 1144 needs more effort and was usually done 1176
 1145 when raw material occurred in low 1177
 1146 abundance or at some distance. Proximity 1178
 1147 to raw material leads to the use of lithic 1179
 1148 tools over a short period because tool 1180
 1149 makers do not need to exert much effort in 1181
 1150 the production of new tools, nor do they 1182
 1151 need to save material by making small tools 1183
 1152 (Andrefsky, 1994). In intragroup points, for 1184
 1153 example, Middle Paleolithic points in our 1185
 1154 research areas, retouch was used for 1186
 1155 achieving symmetry of the edges and 1187
 1156 shaping the lithic points, particularly in 1188
 1157 Mirk, Chah Jam, and Mehran plain. In these 1189
 1158 sites, toolmakers attempted to reduce the 1190
 1159 deviation of symmetry using retouch. So in 1191
 1160 the three sites, the relatively great distance 1192
 1161 to the raw material sources required saving 1193
 1162 raw materials and manufacturing formal 1194
 1163 and symmetrical points (Feizi et al., 2019). 1195
 1164 During the evolution of the point, 1196
 1165 Symmetry points improve projectile 1197
 1166 precision and flight dynamics (Churchill, 1198
 1167 1993). The most important reason is that 1199
 1168 more symmetrical points have a more 1200
 1169 regular flight path than very asymmetric 1201
 1170 points. So that mass imbalance at the distal 1202
 1171 end of the projectile or shape asymmetries 1203
 1172 at the tip leads to an erratic flight path 1204

(Salem and Churchill, 2016). In addition, the more symmetrical point has fewer protrusions (Feizi et al., 2019), which causes to decrease in the drag coefficient and increases its penetration depth (Hughes, 1987). Accordingly, it seems that (2017), the proper symmetry and more regular flight trajectories of an arrow causes to reduce its spin and its deflection and decreasing the oblique contact with the target.

In sum, the law of projectile motion alongside our mathematical method convinced us that significant changes had occurred in the morphology of points since the Middle Paleolithic period. Some morphological changes, such as the least deviation of symmetry and the proportion between width – length and width-thickness that could be among the factors of the drag reduction, occurred in the Upper Paleolithic. Accordingly, in the Middle Paleolithic period, the minimal number of lithic points may have such features. In contrast, we think that the points gradually have become a projectile point for better survival of Homo sapiens. Most of all, this development could be the cognitive development of Homo and, in particular, modern humans.

1205

1206 **Author Contributions:** 1219
 1207 Conceptualization, N.F. Supervision, 1220
 1208 H.V.N. 1221
 1209 1222
 1210 **Funding:** This research is financially 1223
 1211 supported by the Iran National Science 1224
 1212 Foundation (INSF) for postdoctoral 1225
 1213 research, grant number: 97/S/5904. 1226
 1214 **Acknowledgments:** The authors would 1227
 1215 like to thank the anonymous reviewers for 1228
 1216 their constructive comments. We also 1229
 1217 would like to express our gratitude towards 1230
 1218 Dr. K. Roustaei and Dr. A. Javanmard

Zadeh for their generosity to allocate their archaeological materials for this research. The scanning process took place in the Rock Mechanic Lab, Mining Department, Tarbiat Modares University; we thank the lab crew for their help and support.

Conflicts of Interest: The authors declare no conflict of interest.

References

Adams, R., Crouse, W., Carl Jr, E. and Abelson, P.H. eds., 1960. *Mac Graw-Hill Encyclopedia of*

- 1231 *Science and Technology: An International* 1273 applied to back stone tools. *Journal of*
1232 *Reference Work in 15 Volumes Including an Index.* 1274 *Archaeological Science*, 110, p.105011.
- 1233 *Spir-Tou*. McGraw-Hill Book Company. 1275
- 1234 Andrefsky Jr, W., 1994. The geological 1276 Conard, N.J., Ghasidian, E. and Heydari, S.,
1235 occurrence of lithic material and stone tool 1277 2009. The open-air Late Paleolithic site of
1236 production 1278 Bardia and the Paleolithic occupation of the
1237 strategies. *Geoarchaeology*, 9(5), pp.375- 1279 Qaleh Gusheh sand dunes, Esfahan
1238 391. 1280 Province, Iran. *British Archaeological*
1281 *Research International Series*, 1968,
1282 pp.141-154.
- 1239 Ang, D.G., 2013. Shape and size matter for 1283 Coppe, J. and Rots, V., 2017. Focus on the
1240 projectile drag. *J. Adv. Undergrad. Phys.* 1284 target. The importance of a transparent
1241 *Lab. Invest*, 1(2). 1285 fracture terminology for understanding
1286 projectile points and projecting
1287 modes. *Journal of Archaeological Science:*
1288 *Reports*, 12, pp.109-123.
- 1242 Bourot, J.M., 1974. On the numerical 1289 Dockall, J.E., 1997. Wear traces and
1243 computation of the optimum profile in 1290 projectile impact: a review of the
1244 Stokes flow. *Journal of Fluid* 1291 experimental and archaeological
1245 *Mechanics*, 65(3), pp.513-515. 1292 evidence. *Journal of Field*
1293 *Archaeology*, 24(3), pp.321-331.
- 1246 Carlucci, D.E., and Jacobson, S.S., 2018. 1294 Feizi, N., Vahdati Nasab, H. and Wynn, T.,
1247 *Ballistics: theory and design of guns and* 1295 2018. Consider the third dimension: A new
1248 *ammunition*. CRC Press. 1296 approach for measuring the symmetry of
1297 the middle Paleolithic points of the Mirak
1298 Site. *Comptes Rendus Palevol*, 17(6),
1299 pp.388-398.
- 1249 Churchill, S.E. and Rhodes, J.A., 2009. The 1300 Feizi, N., Vahdati Nasab, H. and Wynn, T.,
1250 evolution of the human capacity for "killing 1301 2019. New Approach to Analysis the
1251 at a distance": the human fossil evidence for 1302 Middle Paleolithic Points of the Iranian
1252 the evolution of projectile weaponry. In *The* 1303 Plateau: Style vs. Environment. *Lithic*
1253 *evolution of hominin diets* (pp. 201-210). 1304 *Technology*, 45(1), pp.19-37.
1254 Springer, Dordrecht. 1305 <https://doi.org/10.1080/01977261.2019.1686563>
- 1255 Churchill, S.E., 1993. Weapon technology, 1306 Fischer, A., Hansen, P.V. and Rasmussen,
1256 prey size selection, and hunting methods in 1307 P., 1984. Macro and micro wear traces on
1257 modern hunter-gatherers: Implications for 1308 lithic projectile points: experimental results
1258 hunting in the Paleolithic and 1309 and prehistoric examples. *Journal of*
1259 Mesolithic. *Archeological Papers of the* 1310 *Danish archaeology*, 3(1), pp.19-46.
- 1260 *American Anthropological* 1311 Ghasidian, Elham, 2012, "Rostami Culture
1261 *Association*, 4(1), pp.11-24. 1312 and the Cultural Characteristics of Modern
1313 Paleolithic in Zagros Settlements", Eighty
1314 Years of Iranian Archeology, by Youssef
1315 Hassanzadeh and Sima Miri, Pazineh
- 1262 Clarkson, C., 2016. Testing archaeological 1316
1263 approaches to determining past projectile 1317
1264 delivery systems using ethnographic and 1318
1265 experimental data. In *Multidisciplinary* 1319
1266 approaches to the study of Stone Age 1320
1267 weaponry (pp. 189-201). Springer, 1321
1268 Dordrecht. [https://doi.org/10.1007/978-](https://doi.org/10.1007/978-94-017-7602-8_13)
1269 [94-017-7602-8_13](https://doi.org/10.1007/978-94-017-7602-8_13) 1322
- 1270 Delpiano, D., Zupancich, A. and Peresani, 1323
1271 M., 2019. Innovative Neanderthals: Results 1324
1272 from an integrated analytical approach 1325

- 1316 Publishing, in collaboration with the
1317 Museum National, Tehran.
- 1318 Chadelle, J.P., Geneste, J.M. and Plisson,
1319 H., 1986. Le Solutrén de la grotte de
1320 Combe Saunière 1 (Dordogne). Première
1321 approche paléolithique. *Gallia*
1322 *préhistoire*, 29(1), pp.9-27.
- 1323 Giordano, N.J., 2013. College Physics:
1324 Reasoning and Relationships 2nd edn
1325 (Boston, MA: Brooks/Cole Cengage).
- 1326 Gopher, A., 1994. *Arrowheads of the*
1327 *Neolithic Levant: a seriation analysis* (No.
1328 10). Eisenbrauns.
- 1329 Groucutt, H.S., 2014. Middle Palaeolithic
1330 point technology, with a focus on the site of
1331 Tor Faraj (Jordan, MIS 3). *Quaternary*
1332 *International*, 350, pp.205-226.
- 1333 Hardy, B.L., Moncel, M.H., Daujeard, C.,
1334 Fernandes, P., Béarez, P., Desclaux, E.,
1335 Navarro, M.G.C., Puaud, S. and Gallotti,
1336 R., 2013. Impossible Neanderthals?
1337 Making string, throwing projectiles and
1338 catching small game during Marine Isotope
1339 Stage 4 (Abri du Maras, France).
1340 *Quaternary Science Reviews*, 82, pp.23-40.
- 1341 Hole, F., 1970. The Paleolithic culture
1342 sequence in western Iran. *Actes du VII*
1343 *Congrès de l'UISPP, Bratislava, 1967*,
1344 pp.286-293.
- 1345 Hughes, S.S., 1998. Getting to the point:
1346 evolutionary change in prehistoric
1347 weaponry. *Journal of Archaeological*
1348 *Method and Theory*, 5(4), pp.345-408.
1349 <https://doi.org/10.1007/BF02428421>
- 1350 Iovita, R., Schönekeß, H., Gaudzinski-
1351 Windheuser, S. and Jäger, F., 2014.
1352 Projectile impact fractures and launching
1353 mechanisms: results of a controlled ballistic
1354 experiment using replica Levallois
1355 points. *Journal of Archaeological*
1356 *Science*, 48, pp.73-83.
- 1357 Javanmardzadeh, A. 2016. Tropical project
1358 Report: 20 and 21 grids, Changulee Dam,
1359 Transmission System, the Iranian Center
1360 for Archaeological. Unpublished (in Farsi).
1361 -Lenoir, M., and Villa, P., 2006. Hunting
1362 weapons of the Middle Stone Age and the
1363 Middle Palaeolithic: spear points from
1364 Sibudu, Rose Cottage, and Bouheben.
1365 *Southern African Humanities*, 18(1), pp.89-
1366 122. [https://halshs.archives-](https://halshs.archives-ouvertes.fr/halshs-00437400)
1367 [ouvertes.fr/halshs-00437400](https://halshs.archives-ouvertes.fr/halshs-00437400)
- 1368 Kufel-Diakowska, B., Wilczyński, J.,
1369 Wojtal, P. and Sobczyk, K., 2016.
1370 Mammoth hunting—impact traces on
1371 backed implements from a mammoth bone
1372 accumulation at Kraków Spadzista
1373 (southern Poland). *Journal of*
1374 *Archaeological Science*, 65, pp.122-133.
- 1375 Mehrpoor Moghadam, M., 2009.
1376 Investigation of Throwing Motion of
1377 Middle Paleolithic Points, Using the
1378 Mousterian Arifacts of Mirak Site, Semnan,
1379 Iran (Unpublished dissertation).
- 1380 Mika, A., Flood, K., Norris, J.D., Wilson,
1381 M., Key, A., Buchanan, B., Redmond, B.,
1382 Pargeter, J., Bebbber, M.R. and Eren, M.I.,
1383 2020. Miniaturization optimized weapon
1384 killing power during the social stress of late
1385 pre-contact North America (AD 600-
1386 1600). *Plos one*, 15(3), p.e0230348.
- 1387 Mullen, D., Matney, T., Morrison, A.,
1388 Fisch, M., Buchanan, B. and Bebbber, M.R.,
1389 2021. Experimental assessment of Neo-
1390 Assyrian bronze arrowhead penetration: An
1391 initial study comparing bilobate versus
1392 trilobate morphologies. *Journal of*
1393 *Archaeological Science: Reports*, 35,
1394 p.102765.
- 1395 Newman, K. and Moore, M.W., 2013.
1396 Ballistically anomalous stone projectile
1397 points in Australia. *Journal of*
1398 *Archaeological Science*, 40(6), pp.2614-
1399 2620.
1400 <https://doi.org/10.1016/j.jas.2013.01.023>

- 1401 Odell, G.H. and Cowan, F., 1986. 1444 projectiles. *Thin-Walled Structures*, 123,
1402 Experiments with spears and arrows on 1445 pp.1-10.
- 1403 animal targets. *Journal of Field* 1446 Roper, M., Squires, T.M. and Brenner,
1404 *Archaeology*, 13(2), pp.195-212. 1447 M.P., 2008. Symmetry unbreaking in the
1405 Oteh, U., 2008. *Mechanics of Fluids*. 1448 shapes of perfect projectiles. *Physics of*
1406 AuthorHouse. 1449 *Fluids*, 20(9), p.093606.
1407 Otte, M., Biglari, F., Flas, D., Shidrang, S., 1450 <https://doi.org/10.1063/1.2982500>
- 1408 Zwyns, N., Mashkour, M., Naderi, R., 1451 Rots, V. and Plisson, H., 2014. Projectiles
1409 Mohaseb, A., Hashemi, N., Darvish, J. and 1452 and the abuse of the use-wear method in a
1410 Radu, V., 2007. The Aurignacian in the 1453 search for impact. *Journal of*
1411 Zagros region: new research at Yafteh cave, 1454 *Archaeological Science*, 48, pp.154-165.
- 1412 Lorestan, Iran. *antiquity*, 81(311), pp.82-96 1455 Roustaei, K., 2010. Discovery of Middle
1413 Pétilion, J.M., Bignon, O., Bodu, P., Cattelain, 1456 Palaeolithic occupation at high altitude in
1414 P., Debout, G., Langlais, M., Laroulandie, V., 1457 the Zagros Mountains, Iran. *Antiquity*,
1415 Plisson, H. and Valentin, B., 2011. Hard core 1458 84(325).
- 1416 and cutting edge: experimental manufacture 1459 Salem, P.E. and Churchill, S.E., 2016.
1417 and use of Magdalenian composite projectile 1460 Penetration, tissue damage, and lethality of
1418 tips. *Journal of Archaeological Science*, 38(6), 1461 wood-versus lithic-tipped projectiles.
1419 pp.1266-1283. 1462 In *Multidisciplinary approaches to the*
1420 Pironneau, O., 1973. On optimum profiles 1463 *study of Stone Age weaponry* (pp. 203-212).
1421 in Stokes flow. *Journal of Fluid* 1464 Springer, Dordrecht.
- 1422 *Mechanics*, 59(1), pp.117-128. 1465 Salimipour, S.E., Teymourtash, A.R. and
1423 Plisson, H., 2005. Examen tracéologique 1466 Mamourian, M., 2018. Performance
1424 des pointes aziliennes du Bois-Ragot. *La* 1467 Comparison of Several Air Gun Projectiles
1425 *Grotte du Bois-Ragot à Gouex (Vienne)*. 1468 with Nose Shape Modification. *Modares*
1426 *Magdalénien et Azilien. Société* 1469 *Mechanical Engineering*, 18(3), pp.395-
1427 *préhistorique française (Mémoires, 38)*, 1470 405.
- 1428 *Paris*, pp.183-189. 1471 Sano, K., Arrighi, S., Stani, C., Aureli, D.,
1429 Rios-Garaizar, J., 2016. Experimental and 1472 Boschin, F., Fiore, I., Spagnolo, V., Ricci,
1430 archeological observations of Northern 1473 S., Crezzini, J., Boscato, P. and Gala, M.,
1431 Iberian Peninsula Middle Paleolithic 1474 2019. The earliest evidence for
1432 Mousterian point assemblages. Testing the 1475 mechanically delivered projectile weapons
1433 potential use of throwing spears among 1476 in Europe. *Nature ecology &*
1434 Neanderthals. In *Multidisciplinary* 1477 *evolution*, 3(10), pp.1409-1414.
- 1435 *approaches to the study of Stone Age* 1478 Sears, W.R., 1947. On projectiles of
1436 *weaponry* (pp. 213-225). Springer, 1479 minimum wave drag. *Quarterly of Applied*
1437 Dordrecht. <https://doi.org/10.1007/978-> 1480 *Mathematics*, 4(4), pp.361-366.
- 1438 94-017-7602-8_15 1481 Schoville, B.J., Brown, K.S., Harris, J.A.
1439 Rodriguez-Millan, M., Garcia-Gonzalez, 1482 and Wilkins, J., 2016. New experiments
1440 D., Rusinek, A., Abed, F. and Arias, A., 1483 and a model-driven approach for
1441 2018. Perforation mechanics of 2024 1484 interpreting Middle Stone Age lithic point
1442 aluminium protective plates subjected to
1443 impact by different nose shapes of

- 1485 function using the edge damage distribution
1486 method. *PloS one*, 11(10), p.e0164088.
- 1487 Shea, J., Davis, Z. and Brown, K., 2001.
1488 Experimental tests of Middle Palaeolithic
1489 spear points using a calibrated crossbow.
1490 *Journal of Archaeological Science*, 28(8),
1491 pp.807-816. Doi:10.1006/jasc.2000.0590.
- 1492 Shea, J.J. and Sisk, M.L., 2010. Complex
1493 projectile technology and Homo sapiens
1494 dispersal into western Eurasia.
1495 *PaleoAnthropology*, 2010, pp.100-122.
1496 Doi:10.4207/PA.2010.ART36.
- 1497 Shea, J.J., 1988. Spear points from the
1498 Middle Paleolithic of the Levant. *Journal of*
1499 *Field Archaeology*, 15(4), pp.441-450.
- 1500 Shea, J.J., 2003. Neandertals, competition,
1501 and the origin of modern human behavior in
1502 the Levant. *Evolutionary Anthropology:*
1503 *Issues, News, and Reviews: Issues, News,*
1504 *and Reviews*, 12(4), pp.173-187.
1505 <https://doi.org/10.1002/evan.10101>.
- 1506 Shea, J.J., 2006. The origins of lithic
1507 projectile point technology: evidence from
1508 Africa, the Levant, and Europe. *Journal of*
1509 *Archaeological Science*, 33(6), pp.823-846.
1510 Doi: 10.1016/j.jas.2005.10.015
- 1511 Shea, J.J., 2013. *Stone tools in the*
1512 *Paleolithic and Neolithic Near East: a*
1513 *guide*. Cambridge University Press.
- 1514 Shea, J.J., Brown, K.S. and Davis, Z.J.,
1515 2002. Controlled experiments with Middle
1516 Palaeolithic spear points: Levallois points.
1517 *Experimental archaeology: replicating*
1518 *past objects, behaviors, and processes,*
1519 *1035*, pp.55-72.
- 1520 Sisk, M.L. and Shea, J.J., 2009.
1521 Experimental use and quantitative
1522 performance analysis of triangular flakes
1523 (Levallois points) used as arrowheads.
1524 *Journal of Archaeological Science*, 36(9),
1525 pp.2039-2047. Doi:
1526 10.1016/j.jas.2009.05.023
- 1527 Sisk, M.L. and Shea, J.J., 2011. The African
1528 origin of complex projectile technology: an
1529 analysis using tip cross-sectional area and
1530 perimeter. *International Journal of*
1531 *Evolutionary Biology*, 2011.
1532 Doi: 10.4061/2011/968012.
- 1533 Sitton, J., Story, B., Buchanan, B. and Eren,
1534 M.I., 2020. Tip cross-sectional geometry
1535 predicts the penetration depth of stone-
1536 tipped projectiles. *Scientific Reports*, 10(1),
1537 pp.1-9.
- 1538 Sperrazza, J. and Kokinakis, W., 1968.
1539 Ballistic limits of tissue and
1540 clothing. *Annals of the New York Academy*
1541 *of Sciences*, 152(1), pp.163-167.
- 1542 Thomas, D.H., 1978. Arrowheads and atlatl
1543 darts: how the stones got the shaft.
1544 *American Antiquity*, 43(3), pp.461-472.
1545 DOI: 10.2307/279405.
- 1546 Vahdati Nasab, H., 2010. Paleolithic
1547 archaeology in Iran. *Intl. J*, 18, p.1.
1548 [https://www.researchgate.net/publication/2](https://www.researchgate.net/publication/288263080_Paleolithic_archaeology_in_Iran)
1549 [88263080_Paleolithic_archaeology_in_Ira](https://www.researchgate.net/publication/288263080_Paleolithic_archaeology_in_Iran)
1550 [n](https://www.researchgate.net/publication/288263080_Paleolithic_archaeology_in_Iran).
- 1551 Vahdati Nasab, H., Clark, G.A., and
1552 Torkamandi, S., 2013. Late Pleistocene
1553 dispersal corridors across the Iranian
1554 Plateau: a case study from Mirak, a Middle
1555 Paleolithic site on the northern edge of the
1556 Iranian Central Desert (Dasht-e Kavir).
1557 *Quaternary International*, 300, pp.267-
1558 281.
1559 [https://doi.org/10.1016/j.quaint.2012.11.02](https://doi.org/10.1016/j.quaint.2012.11.028)
1560 [8](https://doi.org/10.1016/j.quaint.2012.11.028)
- 1561 Vahdati Nasab, H., Roustaei, K., Fatideh,
1562 M.G., Shojaeefar, F. and Sarvandi, M.H.,
1563 2017. The first evidence for Late
1564 Pleistocene hominin populations on the
1565 southern Caspian Sea coast. *Antiquity*,
1566 91(355).
1567 <https://doi.org/10.15184/aqy.2016.232>
- 1568 Vahdati, Nasab, H., and Hashemi, M.,
1569 2016. Playas and Middle Paleolithic

1570 settlement of the Iranian Central Desert: the
1571 discovery of the Chah-e Jam Middle
1572 Paleolithic site. *Quaternary International*,
1573 408, pp.140-152.

1574 Villa, P. and Soriano, S., 2010. Hunting
1575 weapons of Neanderthals and early modern
1576 humans in South Africa: similarities and
1577 differences. *Journal of Anthropological*
1578 *Research*, 66(1), pp.5-38.

1579 Vogel, S., 2005. Living in a physical world
1580 V. Maintaining temperature. *Journal of*
1581 *Biosciences*, 30(5), pp.581-590.
1582 <https://doi.org/10.1007/BF02703556>

1583 Vogel, S., 1994. *Life in moving fluids: the*
1584 *physical biology of flow*. Princeton
1585 University Press.

1586 Von Kármán, T., 1963. *Aerodynamics* (Vol.
1587 9). New York: McGraw-Hill.

1588 Wilkins, J., Schoville, B.J., Brown, K.S.
1589 and Chazan, M., 2012. Evidence for early
1590 hafted hunting
1591 technology. *Science*, 338(6109), pp.942-
1592 946.

1593 Wilkins, J., Schoville, B.J. and Brown,
1594 K.S., 2014. An experimental investigation
1595 of the functional hypothesis and
1596 evolutionary advantage of stone-tipped
1597 spears. *PloS one*, 9(8), p.e1045

1598 Wilkins, J. and Chazan, M., 2012. Blade
1599 production~ 500 thousand years ago at
1600 Kathu Pan 1, South Africa: support for a
1601 multiple origins hypothesis for early
1602 Middle Pleistocene blade technologies.
1603 *Journal of Archaeological Science*, 39(6),
1604 pp.1883-1900.

1605 Wilson, J.D. and Buffa, A.J., 2000. *College*
1606 *Physics: Student Study Guide and Solutions*
1607 *Manual*. Prentice Hall.

1608 Wingrove, A.L., 1973. The influence of
1609 projectile geometry on adiabatic shear and
1610 target failure. *Metallurgical*
1611 *Transactions*, 4(8), pp.1829-1833.

Appendix

retouched Mirak points	n	Mean	S.d
Weight (g)	143	12.7	7.6
Area	143	1253	468.5
Length (mm)	143	51.9	10.7
Width at med (mm)	143	24.7	6.4
Max width (mm)	143	28.4	8.1
Thickness at med (mm)	143	7.5	2.5
Max thickness (mm)	143	9.2	4.5
Volume (mm ³)	143	14134	8422.5
Elongation	143	1.99	0.8575
Flattening	143	3.4	1.04
Platform flattening	143	3.4	1.4
Relative platform size(mm ³)	143	185.1	118.9
TCSA	143	132.3	65.1
retouched in Chah-e- jam points	n	Mean	S.d

Weight (g)	57	11.9	7.2
Area	57	1055.4	481.3
Length (mm)	57	42.6	10.4
Width at med (mm)	57	24.6	5.5
Max width (mm)	57	28.2	6.6
Thickness at med (mm)	57	7.6	2.3
Max thickness (mm)	57	9.13	4.3
Volume (mm3)	57	12261.9	8500.5
Elongation	57	1.5	0.3
Flattening	57	3.3	0.9
Platform flattening	57	3.4	1.2
Relative platform size(mm3)	57	196.5	110
TCSA	57	133.5	62.3
Retouched	n	Mean	S.d
Khuhrangh points			
Weight (g)	22	21.1	10.5
Area	22	1719.3	518.3
Length (mm)	22	57.9	9.12
Width at med (mm)	22	28.4	5.04
Max width (mm)	22	28.3	8.04
Retouched	n	Mean	S.d
Khuhrangh points			
Thickness at med (mm)	22	10.9	3.06
Max thickness (mm)	22	15.6	9.6
Volume (mm3)	22	23221.1	10759.7
Elongation	22	2.3	0.9
Flattening	22	2.3	1.1
Platform flattening	22	2.7	0.9
Relative platform size(mm3)	22	268.8	119.9
TCSA	22	195.9	65.09
Retouched Bandepey	n	Mean	S.d
points			
Weight (g)	27	26.7	21.6
Area	27	2060.3	989.6
Length (mm)	27	59.6	15.6
Width at med (mm)	27	31.9	9.4
Max width (mm)	27	37.5	10.7

Thickness at med (mm)	27	10.7	3.9
Max thickness (mm)	27	12.9	3.7
Volume (mm3)	27	33422.2	30027.2
Elongation	27	1.63	0.32
Flattening	27	2.9	0.74
Platform flattening	27	3.02	1.2
Relative platform size(mm3)	27	360.4	223.6
TCSA	27	252.2	133.1
Retouched Mehran points	n	Mean	S.d
Weight (g)	31	13.9	10.5
Area	31	1235.3	604.7
Length (mm)	31	46.3	12.04
Width at med (mm)	31	23.4	7.2
Max width (mm)	31	27.08	7.8
Thickness at med (mm)	31	9.9	5.4
Max thickness (mm)	31	10.25	3.3
Volume (mm3)	31	15286.1	11351.1
Elongation	31	1.8	0.38
Flattening	31	2.7	0.7
Retouched Mehran points	n	Mean	S.d
Platform flattening	31	2.5	0.92
Relative platform size(mm3)	31	180.4	121.1
TCSA	31	148.3	80.1
Unretouched points	n	Mean	S.d
Weight (g)	6	10.1	7.8
Area	6	1013.8	474.6
Length (mm)	6	42.4	7
Width at med (mm)	6	23.5	7
Max width (mm)	6	24.5	8
Thickness at med (mm)	6	8.2	2.9
Max thickness (mm)	6	13.3	12.7
Volume (mm3)	6	12747.9	9453.2
Elongation	6	1.9	0.9
Flattening	6	2.8	1.2
Platform flattening	6	3.4	0.98

Relative platform size(mm3)	6	149.3	56.1
TCSA	6	140.5	82.4

Table 1. Descriptive statistics for Levallois point morphology on sites inside Iran.

retouched Tor Faraj points	n	Mean	S.d
Weight (g)	107	14.4	8.5
Length (mm)	107	54.9	13.4
Width at med (mm)	107	28.2	7.4
Max width (mm)	107	37	9.8
Thickness at med (mm)	107	7.9	2.3
Max thickness (mm)	107	7.9	2.3
Volume (mm3)	107	10788.4	7123.5
Elongation	107	2.0	0.6
Flattening	107	4.7	1.2
Platform flattening	107	6.1	2.1
Relative platform size(mm3)	107	8.9	5.9
TCSA	107	133.4	73.1
Unretouched points			
Weight (g)	90	13.8	8.4
Length (mm)	90	53.9	13.4
Width at med (mm)	90	28.0	7.2
retouched Tor Faraj points	n	Mean	S.d
Max width (mm)	90	36.9	9.7
Thickness at med (mm)	90	6.1	1.9
Max thickness (mm)	90	7.7	2.3
Volume (mm3)	90	10381.0	6699.7
Flattening	90	4.8	1.1
Elongation	90	2.0	0.5
Platform flattening	90	6.1	2.1
Relative platform size(mm3)	90	8.7	0.5
TCSA	90	149.5	72.2
Retouched points			
Weight (g)	17	17.7	11.0
Length (mm)	17	60.5	12.3
Width at med (mm)	17	29.1	8.3

Max width (mm)	17	38.8	10.2
Thickness at med (mm)	17	6.7	2
Max thickness (mm)	17	8.6	2.1
Volume (mm3)	17	12945.4	8979.3
Flattening	17	4.5	1.4
Elongation	17	2.2	0.8
Platform flattening	17	6.2	2.1
Relative platform size(mm3)	17	8.1	3.8
TCSA	17	174.1	76.4

Table 2. Descriptive statistics for Levallois point morphology in Tor Faraj points (Groucutt, 2014).